

CHAPTER 12

INSTRUMENTS AND METERS

Section I-CONSIDERATIONS

12-1. Electrical instruments.

Industry standards define electrical instruments as devices used to measure the present value of electrical quantities under observation. An instrument may be an indicating instrument or a recording instrument. By this definition ammeters, voltmeters, and frequency meters are instruments, not meters.

12-2. Electrical meters.

Industry standards define electrical meters as devices used to measure and register the cumulative value of electrical quantities with respect to time. For example, a watt-hour meter is used to measure and register the amount of average electrical power over a period of time.

12-3. Validity of electrical measurements.

The basis for measurements should be understood.

a. Measurement techniques. Many units measuring ac values will do so using average, peak, or effective values, based on the assumption that the system provides a pure sine wave. With the growing use of solid-state equipment, the waveforms being measured are increasingly less like a pure sine wave. Resulting measurements can be misleading, but such results are not necessarily the fault of the measuring device.

b. Equivalent rms value. Sine-wave measurements have been traditionally based on the effective value or root-mean-square (rms) value. This ac voltage or current (also known as the effective value) is the value of direct current or voltage that will produce the same heating effect. A peak ac value of 1.414 per unit will produce the same heating effect as a 1.0 per unit dc value, if the ac waveform is a pure sine wave. Therefore, instruments and meters may measure the highest instantaneous, (peak) value or the half-cycle average value. These values are converted by calibration into an rms value. None of these techniques work for accurate measurements of distorted voltage and current waveforms resulting from the action of increasing power electronic loads. Since the distorted waveforms can be represented, mathematically as the imposition of harmonic frequencies (integral multiples of the fundamental 60-hertz frequency) these waveforms are considered harmonically distorted in relation to the number of harmonics in-

involved. Power quality is influenced by generated harmonics to the extent that the total harmonic disturbance affects utilization equipment. There is more at chapter 16, section III.

c. True rms values. A variety of true rms sensing devices are in use for voltage and current measurements. They are also recommended for power quality measurements. Such units will be increasingly installed in switchgear as recent trends in power measurements have been toward digital true rms display devices in the interest of accuracy, ease of readout, and accumulation of data.

12-4. Fixed installations of instruments and meters.

Fixed installations of instruments include ammeters, voltmeters, frequency meters, varimeters, power factor meters, wattmeters, and watt-hour meters. In general, these may be single-phase or three-phase devices, suitable for mounting on switchboard panels, consoles, or switchgear cubicles. They are available as either indicating, recording, or integrating meters and instruments. Older installations will probably be the electro-mechanical type. New installations will increasingly be provided with solid-state digital units with self-diagnostic capabilities.

12-5. Portable instruments and meters.

Portable instruments and meters are used for calibration of fixed instruments and meters, trouble shooting, and maintenance work. They should be compared periodically with laboratory standards for accuracy. True rms sensing units should be used. If not available, they should be requisitioned.

12-6. Inspections of instruments and meters.

Instruments and meters should be visually inspected periodically to determine that they are clean and that their contact surfaces are free of corrosion; that nuts and binding posts are firmly tightened; and that wire, cable, and leads are adequate, neatly arranged, and properly insulated.

12-7. Tests of instruments and meters.

The schedules for the calibration and tests of instruments and meters are dependent, to a great extent, upon the particular installation. When precision is not essential, the period between tests is not critical and may be assigned as convenient. Switchboard

graphic instruments, revenue watt-hour meters, and similar equipment should receive calibration tests at a minimum of every 4 years. Units provided

with built-in diagnostic capabilities should be checked when their associated power apparatus is checked.

Section II-PREVENTIVE MAINTENANCE

12-8. Mounting of instruments and meters.

Instruments and meters, designed for permanent installation, are available for either flush or projection mounting. Proper mounting can be a major factor in reducing the amount of maintenance that will be required. A minimum of vibration should be ensured in the mounting location and design. Vibration is a problem, especially with solid-state units. Shock-resistant mountings may be necessary, if the panel on which the instrument is mounted is subject to shock, as caused by the operation of heavy switchgear. Locations where strong magnetic fields exist (in proximity of heavy current-carrying conductors), should be avoided if accuracy is to be attained.

12-9. Installation of instruments and meters.

Check the installation if repeated problems occur. Extreme temperatures or excessive moisture may not have been taken into account when the installa-

tion was made. Units should always meet code-access requirements and be protected from mechanical damage.

12-10. Maintenance of instruments and meters.

Accuracy tests, repairs, calibrations, and adjustments of instruments and meters should be performed only by personnel trained and qualified for this type of work, or done under the immediate supervision of such personnel. Where activities do not have such specialists on board, arrangements should be made with a nearby activity equipped for this type of work; with local electric power companies on a maintenance contract basis; or through use of manufacturer's service shop facilities. It should be recognized that accuracy requirements for meters should be appropriate for the use to which readings and records are put, and that the cost of high accuracy must be economically justified.

Section III-CALIBRATION AND ADJUSTMENT

12-11. Accuracy check of instruments and meters.

The measurement of values in ac circuits is sometimes quite complex because of harmonic content, phase shifts of voltage versus current, or a combination of both of these factors. Additional loads on various phases may be unbalanced with respect to both loads and phase shifts. Take these conditions into account if true rms measuring devices are not used and the input source provides harmonics.

a. Instruments. The accuracy of observed readings depends partly on the construction of the instrument involved and partly on the skill of the observer. It is generally recommended that an instrument with a knife edge pointer be used in conjunction with a mirror to avoid parallax. The accuracy of the observed reading of any analog instrument varies with the deflection of the instrument; that is, the larger the deflection, the greater the accuracy. For example, consider an instrument with a scale reading of 100, divided into 100 divisions, which is accurate to plus or minus one division. A reading of 20 on this instrument has a margin or error of plus or minus one division, which means that the true value could be between 19 and 21, an actual variation of 10 percent. This empha-

sizes the necessity of selecting an instrument for a test such that the readings are on the high end of the scale.

b. Meters. The accuracy of an adjusted meter will remain practically unchanged for a long period, unless it is subjected to rough handling, heavy overloads for an extended period, or lightning surges. The best method of checking meter accuracy is obtained in the phantom load tests shown in figures 12-1 and 12-2. However, a quick determination of the accuracy of a watt-hour meter under steady load can be obtained by measuring the time required for a certain number of meter disk revolutions. For instance, if it takes "t" minutes for the meter disk to make "r" revolutions, the average power "W" is given in equation 12-1.

$$W = \frac{W = K \times r \times 60}{t} = \text{watts} \quad (\text{eq. 12-1})$$

"K" is the watt-hour constant and is stamped on the meter nameplate. The power flow determined by this method should be compared with the reading of a digital true rms watt-hour meter connected in parallel with the watt-hour meter being checked.

12-12. Adjustment of instruments and meters.

The instrument or meter to be adjusted should be disconnected from its normal circuit before any

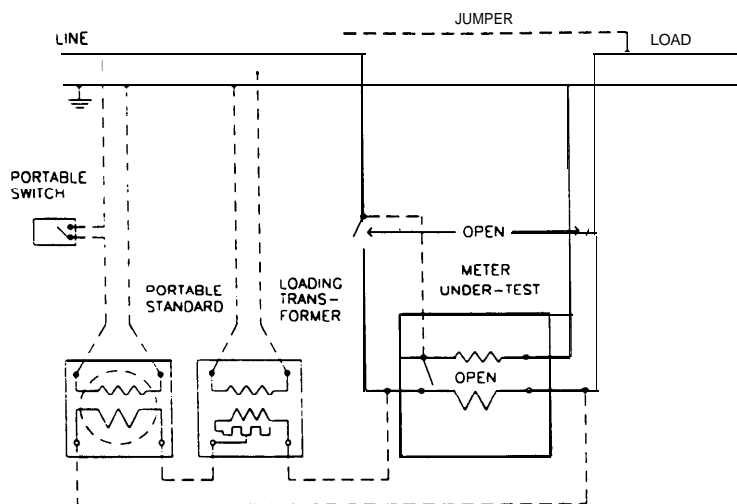


Figure 12-1. Method of connecting a phantom load for a field test, if on a single-phase, two-wire watt-hour meter

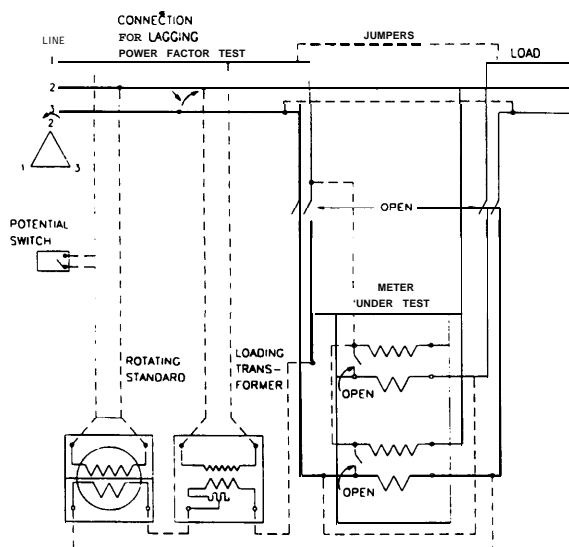


Figure 12-2. Method of connecting a phantom load for field test, if on a three-phase, three-wire watt-hour meter

work is done on it. Careful planning of the work will reduce the chances of an accident from energized equipment.

a. Preparation. Before making adjustments on instruments or meters that require removal of the cover, it is important that the outside of the instrument be thoroughly cleaned to prevent the entrance of any dirt, dust, or magnetic material. Also, the working space around the instrument or meter should be cleared to permit setting up test devices required for calibration and adjustment. Test devices should not be placed directly under the equipment to be adjusted.

b. Procedure for instruments. Adjustment procedures will vary according to the type of instrument. The manufacturer's instrument book should be consulted before making any adjustment. Adjustments

for solid-state units may be different from the following general data applying to electromechanical units. Some adjustments of fixed instruments can be made without removal from their panel assembly mounting. Other adjustments, however, require that the instrument be taken to a shop or laboratory. All instruments should be adjusted for null (zero) reading. In most cases, this reading can be obtained with the instrument disconnected. For watt and varmeters, the null reading should be checked with only the current coil energized from a test source. The full scale adjustment should be obtained by slowly increasing the load to be measured to the full scale value. For example, a voltmeter is adjusted by varying the series resistance connected to the test power supply. Watch the pointer as the instrument is slowly loaded to its full scale value to check whether there is any friction in the movement. When a watt or varmeter is being adjusted, an ammeter should be used in series with the current coil of the meter and the current should be limited to the rating of the coil to prevent overheating. After the instrument has been calibrated and adjusted for full scale reading, the load should be gradually decreased and the null position checked again.

c. Procedures for meters. Meter adjustments are made for full load, light load, lag, and creep. Most polyphase meters have an additional adjustment to obtain balance between elements. The meter manufacturers' instruction book should be consulted for instructions before making any adjustments. General instructions given here may differ from manufacturers' instructions for solid-state meters. The lag and balance adjustments are usually made in a shop before installation. The adjustment of a meter is done by loading it with a phantom (artificial) load and comparing its performance with that of a cali-

brated portable standard meter. The test connections are shown in figures 12-1 and 12-2.

(1) *Full load adjustment.* The full load adjustment in most meters is accomplished by changing damping magnet positions. This involves changing the position of the magnetic shunt to vary the amount of flux passing through the disk. The change produced in the registration, expressed in percentage is practically the same on all loads. Thus, if the registration is 98 percent at both full load and light load, shifting the full load adjustment to increase the speed 2 percent will make the meter correct at both loads. The duration of the test at full load should be 10 revolutions of the meter disk.

(2) *Light load adjustment.* The light load adjustment is made by varying the amount of friction compensating torque. The effect of this is inversely proportional to the load, so twice as much torque is required at 5 percent load as at 10 percent load, or one-tenth as much at full load as at 10 percent load. Generally, when a meter is inaccurate at light load, more than compensation is required to correct the problem. In such cases, the tester should locate and correct the problem, and again check the accuracy before attempting adjustment. The light load test should be made at 10 percent of full load for a duration equivalent to two revolutions of the meter disk.

(3) *Lag or phase adjustment.* The lag or phase adjustment is ordinarily made in the shop as part of the routine test of all ac meters. Facilities for this test are readily available in the shop, and once the adjustment is made, it will not change significantly in service. The test to determine the lag or phase

adjustment is generally made at 50 percent power factor, with rated current and voltage applied. Fifty percent power factor is generally used, because it can be readily obtained from a polyphase circuit without auxiliary equipment.

(4) *Creep adjustment.* Creep is the continuing rotation of a meter disk at no load for at least one complete revolution. Creep may occur either as backward or forward motion. Although only a rapid rate of creeping will result in appreciable registration of watthours, no meter should be allowed to creep continuously. When load is removed, a meter will generally rotate for a part of a revolution before coming to rest. This is not creep. Leakage or grounding in the load circuit may also cause a turning of the rotation element, which may be mistaken for creeping. Most induction meters are designed with holes or slots cut in opposite sides of the disk to prevent creeping. To locate the problem causing creeping, check the meter for evidence of:

- (a) Incorrect compensation for friction.
- (b) Vibration.
- (c) Stray fields (internal or external).
- (d) High voltage, that acts to overcompensate.
- (e) Incorrect connection of the potential circuit. For example, the potential circuit is connected on the load side of the meter, when the adjustment has been made for connection to the service side of the meter.
- (f) Short circuits in the current coils.
- (g) Mechanical damage or disarrangement of the electromagnetic circuit.

Section IV-REPAIRS

12-13. Field repairs of instruments and meters.

Minor replacement of parts, such as dial faces, pointers, bearings and pivots, chart paper, and meter registers, may be made in the field. If extensive repairs are required, they should be made in a shop. When meter bearings or registers are replaced, recalibration of the meter is required.

12-14. Shop repairs of instruments and meters.

Reference should be made to the manufacturer's instruction books for methods of assembly and adjustment. After parts have been replaced, meters or instruments should be recalibrated. The methods to be followed are given in section III.

a. *Overhauling.* Major repair of a meter or instrument should be performed in a shop.

(1) *Instruments.* Repair of instruments should not be undertaken, except by qualified personnel

equipped with proper tools. The manufacturer's instruction book should be consulted when making major repairs and when overhauling instruments. After the work is completed, the instrument should be adjusted and checked for accuracy.

(2) *Meters.* The following steps should be taken when a meter is brought to a shop for a complete overhaul:

- (a) Take an initial reading, known as an "as found" reading as an accuracy check, and record the data.
- (b) Clean the meter thoroughly, removing any dust or dirt with special attention to the magnet poles.
- (c) Remove and examine the register to detect any defects that may prevent its correct registration. The worm or pinion on the shaft should be examined to see that it matches properly with the register wheel, which it drives. A slight amount of

play is necessary to prevent excessive friction. When the pinion or worm is short, or the worm is concave to match the curvature of the worm wheel, the height of the moving elements should be set so that the worm and pinion do not bind. For cleaning the pinion or worm, a small stiff brush or a sharpened piece of soft wood may be used.

(d) If the light load test indicated friction, clean all bearings and replace if necessary.

(e) Check the position of the disk in relation to the magnet poles. Center and align if necessary.

(f) Calibrate the meter, making all necessary adjustments described previously.

(g) Clean the cover and examine for defects. Replace gasket washers if necessary.

(h) When work is complete, take a reading, known as an "as left" reading, and record the data.

b. Lubrication. Use lubricants on electromechanical units with extreme caution.

(1) *Instruments.* The shafts of indicating instruments are usually supported by pivot bearings, which normally do not require lubricating.

(2) *Meters.* If the bearings of meters become defective, friction will be increased causing the meter to run slow. The function of the top bearing is to act as a centering guide. Excessive friction on this

bearing may be caused by undue wear, corrosion, or rubbing. Clean and lubricate or replace parts as required. The lower bearing assembly ordinarily consists of a stationary sapphire jewel with a pivot on the rotating element, or two jewels with a steel ball between them. Excessive friction here may be caused by damaged or grooved jewels, worn or defective balls or pivots, or the presence of foreign material on the jewel. When replacing a sapphire bearing, pivots and balls should both be replaced since they have probably been damaged by rough bearings. When the jewel is still perfect, the pivot or ball may be worn. Do not use your hands to manipulate balls and pivots which can be damaged by such handling. Pivots can be inserted with a wrench provided for that purpose. Balls may be inserted into bearings by use of a ball dropping device. The lower bearing should be oiled by filling the bearing cup with an oil recommended by the manufacturer, but lower bearings of the ball type should never be oiled. Care should be taken not to mix oils of different characteristics. Several manufacturers make oil and special oilers for jewels and synchronous timers. Cleaning fluids are also available from several commercial sources to remove dirt and grit from bearings and balls.

Section V-TROUBLESHOOTING

12-15. Temperature influence on instruments and meters.

Almost all electromechanical instruments are influenced by temperature changes to some degree. Take this into account when recording instrument readings.

a. Direct-current instruments. The temperature error of dc voltmeters is principally due to changes in the tension of the springs. The change in electrical circuit resistance of a high grade voltmeter is usually negligible, since this circuit consists of resistance wire having an extremely low temperature coefficient. Direct-current ammeters usually have higher temperature coefficients than voltmeters, because their electrical circuits are composed chiefly of low-resistance copper.

b. Alternating-current instruments. The movable iron voltmeter designed for use at commercial voltages has a very small temperature coefficient, which normally does not need to be taken into account. An increase of temperature lowers both the permeability of the iron and the torque, and at the same time reduces both the strength of the spring and the counter torque by nearly the same amount.

Hence, these ammeters are virtually independent of ordinary temperature changes. Electrodynamicometer type instruments have controlling springs that are the only important element with respect to the temperature coefficient. Such instruments will read slightly lower at temperatures below that at which they are calibrated. The temperature effect on modern ac portable standard watt-hour meters is negligible throughout the normal temperature range.

12-16. Stray-field influence on instruments and meters.

Stray fields produced by other instruments, by conductors carrying heavy currents, and by generators and motors may cause an appreciable error in instrument readings. Even nonmagnetized masses of iron may influence the flux in an instrument. When it is necessary to make tests in places subject to strong stray fields, the instrument should be read, then turned 180 degrees, read again, and an average taken. Some instrument of the electrodynamicometer type are made astatic (independent of position), in order to avoid the errors caused by stray fields. Two movable coils are connected so that

any torques produced by a stray field are equal and opposite.

12-17. Calibration of instruments and fields.

The frequency of calibrating instruments and meters depends on the use and accuracy desired. If calibration standards and equipment are not available, instruments and meters of nearly the same rating can be checked against one another. When wide discrepancies are noted, the instrument or meter that is obviously incorrect should be recalibrated and any needed repairs made.

12-18. Other instrument and meter considerations.

Most troubles have simple causes and may be easily corrected.

a. Indicating instruments. Table 12-1 indicates causes and remedial actions for common troubles that might occur with respect to indicating instruments.

b. Recording instruments and meters. Table 12-2 indicates causes and remedial actions for common troubles that might occur with respect to recording meters and instruments.

Table 12-1. Troubleshooting chart for indicating instruments

Trouble	Cause	Remedial action
No indication,	Instrument disconnected	Check external connections.
	Internal open circuit	Check for circuit continuity.
	Moving element jammed	Check alignment of movement.
	Internal short circuit.	Check internal connections.
Sluggishness or incorrect indication	Tight bearings.	Clean or replace bearings.
		Adjust bearing bushing.
	Dirty	General cleaning.
	Rubbing.	Check alignment and movement.
		Look for bent pointer.
	Corrosion.	Replace bearings if corrosion shows. Clean and give acid bath to part involved or replace.
	Increased friction	Pointer riding on scale due to warped scale.
		Spring touching. Magnetic dust in air gap.

Table 12-2. Troubleshooting chart for recording instruments and meters

Trouble	Cause	Remedial action
Chart stopped	No driving power	Check power source.
	Broken drive train.	Repair or replace drive train.
	Chart jammed	Check paper alignment.
No ink record.....	Ink well empty	Fill well and clean pen.
	Broken ink tube	Replace tube.
	Broken pen	Replace pen.
	No pen contact.	Adjust pen holder.
	Plugged pen	Clean pen.
No registration	Open gear train.	Check gear and pinion alignment.
	Broken gears	Replace gears.
	Jammed register.	Replace register.
	Meter disconnected	Check external electrical connection.
	Internal open circuit	Check for circuit continuity.
Inaccurate readings.	Needs adjustment.	Check with standard and adjust.